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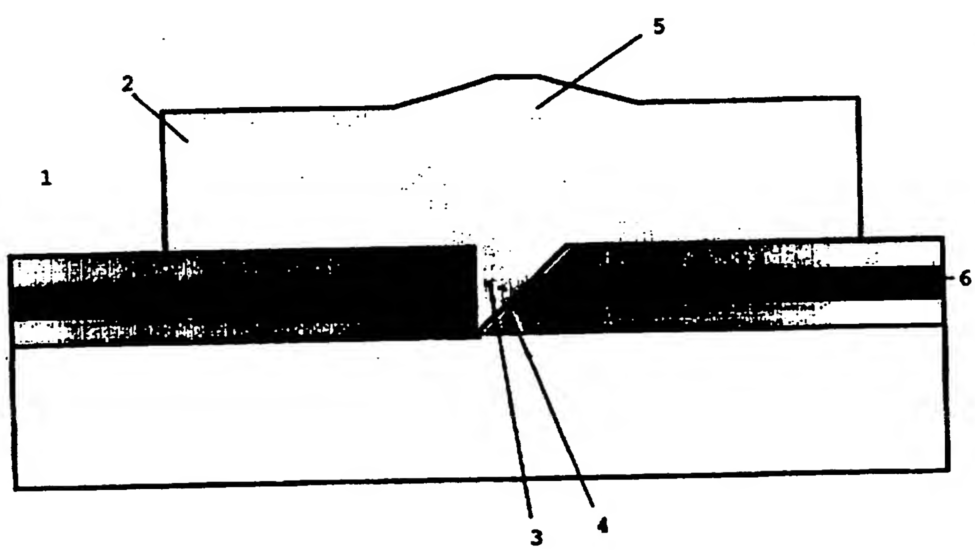
(54) Title: CONNECTOR FOR POLYMERIC OPTICAL WAVEGUIDE STRUCTURES



(57) Abstract

The invention is directed to a connector (1) for polymeric optical waveguide structures (6) comprising an optically transparent article (2) having a protruding right-angled triangular shape (3), which optically transparent article (2) has a stop (12) making a right angle α with the adjacent side (13) of the right-angled triangular shape (3), and the adjacent side (13) having a length h adapted to the desired penetration into the polymeric optical waveguide structure. With the connector according to the invention coupling can be effected by placing the connector on top of a waveguide structure, with the right-angled triangular shape embossed in the waveguide structure. Vertically embossing the right-angled triangular shape in the waveguide structure results in a smooth mirror structure which guides light into or out of the waveguide structure with good coupling efficiency. Vertical coupling permits a three-dimensional optical interconnection to be made between different layers or boards. Connectors according to the invention are suitable for various applications such as Optical Surface Mounting of functional components on waveguide structures such as optical boards and Optical Backplanes.

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CONNECTOR FOR POLYMERIC OPTICAL WAVEGUIDE STRUCTURES

The invention relates to means for coupling light into and out of polymeric optical waveguide structures. In WO 90/02349 a hot knife is used to carve a notch into a polymeric optical fibre. Said notch acts as a mirror structure and guides light out of or into the optical fibre. In J. Lightwave Technol. 6 (1988), 1034 the formation of mirror structures are made in multilayer polyimide structures by means of ion milling. In H. Takahara, S. Matsui and S. Koike, "Optical interconnection between flip-chip bonded photodiodes and optical polyimide waveguides on an opto-electronic multichip module", LEOS 1994 Summer Tropical Meeting Digest on Optical Networks and their enabling technologies, pp. 56-57, July 11-13, Lake Tahoe, 1994, and H.Tahahara, S. Koike, S. Yamaguchi and H. Tomimuro, "Optical waveguide interconnections for opto-electronic multichip modules", Proceedings SPIE, Vol. 1849, Optoelectronic Interconnects, pp. 70-78, 1993, 45 °mirror structures are created in polymeric material by reactive etching. In B.Booth, "Polymers for integrated optical waveguides", in Polymers for Electronic and Photonic applications (C.P. Wong ed.), Academic Press, Inc., San Diego, 1993, pp. 549-599, the formation of 45° mirrors by microtoming and laser ablation is mentioned.
In JP-A-83/171019 an optical fibre branching device is described which is used to couple light into and out of a polymer optical fibre with comparatively large cores.

Although techniques like microtoming, reactive ion etching and ion milling, may give mirror structures with a smooth surface and thus a good coupling efficiency, these techniques are difficult, expensive, time consuming, not very versatile and hard to control. With other, simpler, techniques such as carving with a hot knife, the coupling efficiency leaves much to be desired, especially in the case of monomode waveguide devices. This is also the case with the branching

device of JP-A-83/171019. Said device is embossed into a polymeric optical fibre with a relatively large core (appr. 1000 μm). However, the penetration into the fibre cannot be controlled accurately with this branching device. This is not a problem when a polymer optical fibre of large core diameter is used but, the branching device is not suitable for use in planar waveguides or in fibres with a small core diameter (2-60 μm), let alone in monomode waveguide structures which have a core diameter of at most 10 μm.

The invention has for its object to provide means for coupling light into and out of polymeric waveguide structures, with the coupling being effected in an easily reproducible way, and with good coupling efficiency.

The invention is directed to a connector (1) for polymeric optical waveguide structures (6) comprising an optically transparent article (2) having a protruding right-angled triangular shape (3), which optically transparant article (2) has a stop (12) making a right angle α with the adjacent side (13) of the right-angled triangular shape (3), and the adjacent side (13) having a length h adapted to the desired penetration into the polymeric optical waveguide structure.

With the connector according to the invention coupling can be effected by placing the connector on top of a waveguide structure, with the right-angled triangular shape embossed in the waveguide structure. Embossing the right-angled triangular shape into the waveguide structure results in a smooth mirror structure which guides light into or out of the waveguide structure with good coupling efficiency.
The stop makes sure that the penetration can be accurately controlled. The fact that the stop makes a right angle with the adjacent side guarantees a perpendicular penetration and thus a good coupling efficiency. By setting the length h of the adjacent side, the penetration will be accurately controlled.

With the connector of the invention vertical coupling out of the plane of the optical waveguide structure can be achieved. Especially when coupling planar polymeric waveguide structures, this vertical coupling has several advantages. The first of these is that no end-facets are necessary for the coupling. Polymeric waveguide structures are usually provided with end-facets by means of polishing, laser ablation, reactive ion etching or microtoming. As stated above, these techniques are difficult, expensive, time consuming, not very versatile and hard to control. With the connector of the invention coupling can be effected by simply embossing the connector in the waveguide structure. Accordingly, the waveguide structures themselves do not have to be processed. This is an important advantage because the standard techniques to realise vertical coupling structures usually limit the versatility of polymer waveguide structures, for instance, the size of the boards is limited by the size of the vacuum reactor in which reactive ion etching is performed. When the connector is integrated on the device that will be surface mounted on the waveguide board, the size of the board is not limited by the process. In other cases such as the realisation of vertical couplers by microtoming as described in the above-mentioned articles of Booth coupling can only be made at the edges of the waveguide structure. Vertical coupling permits a three dimensional optical interconnection between different layers or boards. Further, as with the connector of the invention interconnection ports may be realised over the entire surface of the waveguide structure, instead of only at its outer sides of the waveguide structure, a higher density of functional components may be obtained. Connectors according to the invention are suitable for various applications such as Optical Surface Mounting of functional components on waveguide structures such as optical boards and optical backplanes, as will be described later.

In the case of laser ablation and microtoming it is necesarry to provide the mirror structure with a reflective coating in order to

obtain satisfactory coupling efficiency, while in the case of reactive ion etching it is not possible to provide the mirror structure with a reflective coating, which causes a reduced coupling efficiency. In the connectors according to the invention the hypotenuse of the triangular shape may be provided with a reflective coating in order to improve the coupling efficiency. However, in some embodiments of the invention no coating is required to obtain 100% reflection. In this cases one uses total internal reflection at the slanted connector/waveguide structure mirror interface. Total internal reflection may be obtained if the connector is made of material with a high refractive index such as silicon. The hypotenuse may also be provided with a wavelength selective coating, which makes it possible to use the connector for wavelength division multiplexing and demultiplexing.

Although mirror structures making an angle of 45 ° with the waveguide structure give an optimal deflection of light, it is not strictly necessary to have 45 ° mirror structures. It was found that the connectors according to the invention still have a satisfactory deflection of light when the hypotenuse of the triangular shape makes an angle of 30° to 60 ° with the right angle of the triangular shape.

In this description the term right-angled triangular refers to shapes having two sides and a base, which base forms an integral whole with the article. One of the sides makes a right angle with the base of the triangle and is referred to as the adjacent side. The other side (the hypotenuse) may be curved, for instance parabolic. When using connectors having a triangular shape with a parabolic side, the light guided out of the waveguide can be collimated.

The connector according to the invention may be provided with functional components such as (micro)lenses, detectors, light sources, etc. These may be monolithically integrated with the coupler, but also hybrid integration may be used.

If the right-angled triangular shape of the connector is wide enough, the connector can be used to couple more than one waveguide structure. In this case, of course each coupling site may be provided with specific functional components. See Figure 3 which will be further elucidated below. For instances, a connector according to this embodiment may be used, in combination with electronics for detecting light, as a receiver. When used for coupling light into the waveguide structure, this embodiment, in combination with a light source such as a laser diode or a LED, may be used as a transmitter (Figure 4).

The connector according to the invention may also be provided with more than one protruding right-angled triangular shape. In this case, the coupling out of the waveguide is combined with coupling back into the waveguide structure. This embodiment of the invention is highly suitable for applications such as Optical Surface Mounting of functional components on optical boards and optical backplanes. The light is guided out of the waveguide structure to a functional component and after processing guided back into the waveguide structure. The functional component may be optical (an optical isolator, optical amplifier, optical modulator, etc.), or it may comprise an electronic system wherein the optical signal is transformed into an electric one, which electric signal is processed and then transformed into an optical signal and guided back into the waveguide structure. Examples are receiver-transmitters, repeaters, and board-to-board interconnects via optical backplanes. If the connector has protruding right-angled triangular shapes on both sides of the article, the connector may be used for three-dimensional coupling between different optical waveguide layers or boards. See Figure 6, which will be further elucidated below. It is also possible to use two connectors placed on each other to obtain coupling between two waveguide structures. See figure 9 and 10, which will be further elucidated below.

In order to obtain passive alignment of the connectors with respect to the waveguide structures, the connector and/or the waveguide structure may be provided with alignment structures. These may take the form of stubs on the connector which fit into pits of the waveguide structure. The waveguide structures may also be provided with gullies for the triangular shapes.

The connector according to the invention may be used on all kinds of polymeric waveguide structures such as polymer optical fibres, planar optical waveguide devices, polymer optoboards, flexible waveguide ribbons. Planar optical waveguide structures are preferred, because in this case a stable coupling may be achieved. The connectors according to the invention are pre-eminently suitable for use monomode waveguide structures. In monomode waveguide structures (either fibres or planar) the core has a diameter of at moste 10 μm. It goes without saying that for coupling out light from monomode waveguides, it is necessary that the penetration can be controlled very accurately. As the connectors according to the invention comprise a stop and the adjacent side has a length h which can be set very accurately, even in monomode waveguides an excellent coupling can be obtained. In order to improve the mechanical stability of the coupling, the connector may be fixed on the waveguide structure by the aid of an adhesive, but also solder joints or bumps can be used. In general, the connectors are used for coupling planar polymeric waveguide structures (optical boards) wherein the channels can be defined by various methods such as photobleaching, reactive ion etching, photopolymerisation etc.

The connector according to the invention may be made of any material as long as it is hard, transparent in the suitable wavelength area, and processable. Examples of suitable materials are quartz, glass, silicon, saphire, InP, GaAs, and hard plastic. Silicon is preferred because Si-wafers are readily available and have reproducible material constants, are transparent in the wavelength areas of 1300 nm and 1500

nm, which are the wavelengths generally used for optical communications, and can be accurately processed with fairly standard micro-electronic processing techniques. Another advantage of the use of silicon is that due to the high refractive index of Si, total internal reflection takes place at the deflecting interface, so that 100 % deflection efficiency is obtained. If a lower reflectance is required, anti-reflecting coatings should be applied.

As an example, the fabrication of silicon connectors according to the invention comprises the steps of:

1. Dry etching a silicon substrate to obtain a flat vertical surface. This is generally done with a $SiCl_4$ reactive ion etching process and using a metal masking layer.
2. Wet etching the silicon substrate to obtain a flat sloped surface using a hot KOH/H_2O/isopropyl alcohol solution. This results in a reproducible crystallographically defined etching profile. The angle of the slope is 54 °, which was found to result in a good coupling efficiency. Slopes of 45 ° are also obtainable using custom Si-wafers with another crystallographic orientation. Such wafers are commercially available from, for instance, Semiconductor Processing Company, Boston, MA).
3. Cleaving, sawing or etching the processed Si-wafer in individual dices, ready for embossing in polymeric waveguides.

The invention and the various embodiments of the invention are further illustrated in Figures 1 to 10:(the figures are for clarity not on scale). These drawings are presented for purposes of explanation only, and should not be considered limitative in any way.

Figure 1 gives cross-section of a connector according to the invention.
Figure 2 gives a cross-section of a connector according to the

invention which is embossed in a waveguide structure.

Figure 3 gives a schematic view of a connector suitable for coupling light from more than one waveguide structure.

Figure 4 gives a schematic view of a connector combined with an opto-electronic device and electrical leads in a package for optical surface mount applications.

Figure 5 gives a schematic view of a connector for coupling both into and out of a waveguide structure.

Figure 6 gives a cross-section of connectors according to the invention used for three-dimensional coupling between layers or boards.

Figure 7 gives a schematic view of a set of connectors according to the invention which are used for optical back planes.

Figure 8 gives a cross-section of a connector fabricated in Si embossed in a polymer optical waveguide.

Figure 9 gives a cross-section of two connectors which are used to couple two free-standing (flexible) polymeric waveguides.

Figure 10 gives a cross-section of two connectors which are used to couple a free-standing (flexible) polymeric waveguide to an optical board.

In Figure 1 a connector (1) comprising an optically transparant article (2) having a protruding right-angled triangular shape (3), which optically transparant article (2) has a stop (12) making a right angle α with the adjacent side (13) of the right-angled triangular shape (3), and the adjacent side (13) has a length h which is adapted too the desired penetration into the polymeric optical waveguide structure.

In Figure 2 a connector (1) comprising an optically transparant article (2) having a protruding right-angled triangular shape (3) is embossed in a planar polymeric optical waveguide structure (6). The hypotenuse (4) of the right-angled triangular shape forms a mirror

structure. As can be seen in the figure the penetration is set by the length h of the adjacent side (13) of the right-angled triangular shape. In this embodiment the connector is provided with a lens (5).

Figure 3 depicts a connector (1) having a protruding right-angled triangular shape (3) which is wide enough for coupling light from more than one waveguide structure.

Figure 4 shows a module that can be used for surface mounting of opto-electronic components (14) such as surface emitting lasers and detectors on a waveguide board. The housing (15) in which the connector is mounted is also provided with electrical leads (16) for contacting the opto-electronic device) which allow connection with the electrical lines on top of the waveguide board (electro-optical board). The electrical leads are provided with bump connections (17) for electrical contact with the opto-electronic component.

In Figure 5 a connector is given wherein the light is first coupled out of the waveguide structure and then the light is coupled back into the waveguide structure.

In Figure 6 it is shown how the connectors according to the invention may be used for three-dimensional coupling between layers or boards. As can be seen in this figure, the connector has several protruding right-angled triangular shapes on both sides of the article, with the light being coupled from one layer into another.
In Figure 7 a set of connectors (1) is given which may be mounted on an optical waveguide structure acting as an optical backplane.
In Figure 8 a connector (1) made of silicon is given which is embossed into a waveguide structure. The connector is fixed to the waveguide structure with glue (7), and is provided with an antireflective coating (8).

In Figure 9 two free-standing (flexible) waveguides (9) are coupled with two connectors (1) which are provided with alignment structures (9). The free-standing (flexible) waveguide is embossed by the connector with the help of a hold-down plate (10).
In Figure 10 a free-standing (flexible) waveguide (9) is coupled to a planar polymeric optical waveguide structure (6) on a substrate (11).

Claims:

1. A connector (1) for polymeric optical waveguide structures (6) comprising an optically transparent article (2) having a protruding right-angled triangular shape (3), which optically transparant article (2) has a stop (12) making a right angle α with the adjacent side (13) of the right-angled triangular shape (3), and the adjacent side (13) having a length h adapted to the desired penetration into the polymeric optical waveguide structure.

2. A connector according to claim 1 wherein the hypotenuse (4) of the triangular shape is provided with a reflective coating.

3. A connector according to claim 1 or 2 wherein the hypotenuse of the triangular shape makes an angle β of from 30° to 60 ° with the right angle of the triangular shape.

4. A connector according to claim 1 or 2 wherein the triangular shape is parabolic.

5. A connector according to anyone of claims 1-4 wherein the top of the article is provided with a lens (5).

6. A connector according to anyone of claims 1-5 wherein the article is provided with a detector and/or a light source.

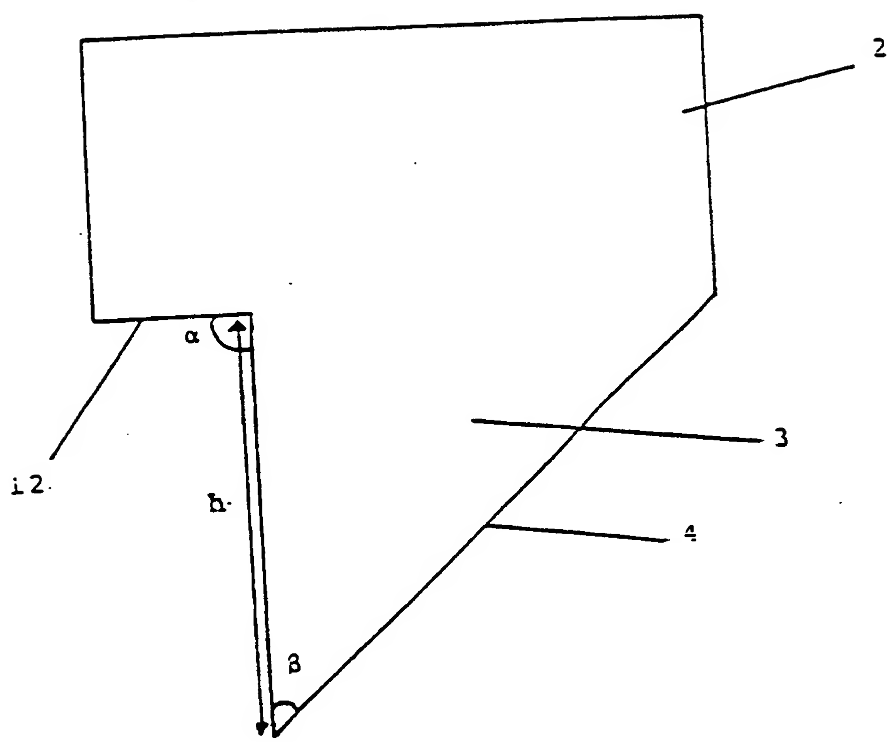
7. A connector according to anyone of claims 1-6 wherein the article has more than one protruding right-angled triangular shape.

8. A connector according to anyone of claims 1-7 wherein the connector is made of silicon.

9. A process for coupling polymeric waveguide structures wherein a connector as described in claims 1-8 is embossed vertically in the waveguide structure.

10. A process for the preparation of a connector according to claim 7, comprising the steps of:
   - dry etching a silicon substrate with $SiCl_4$ reactive ion etching using a metal masking layer,
   - wet etching the silicon substrate to obtain a flat sloped surface using a hot KOH/H_2O/isopropyl alcohol solution,
   - cleaving, sawing or etching the obtained structure.

FIG.1



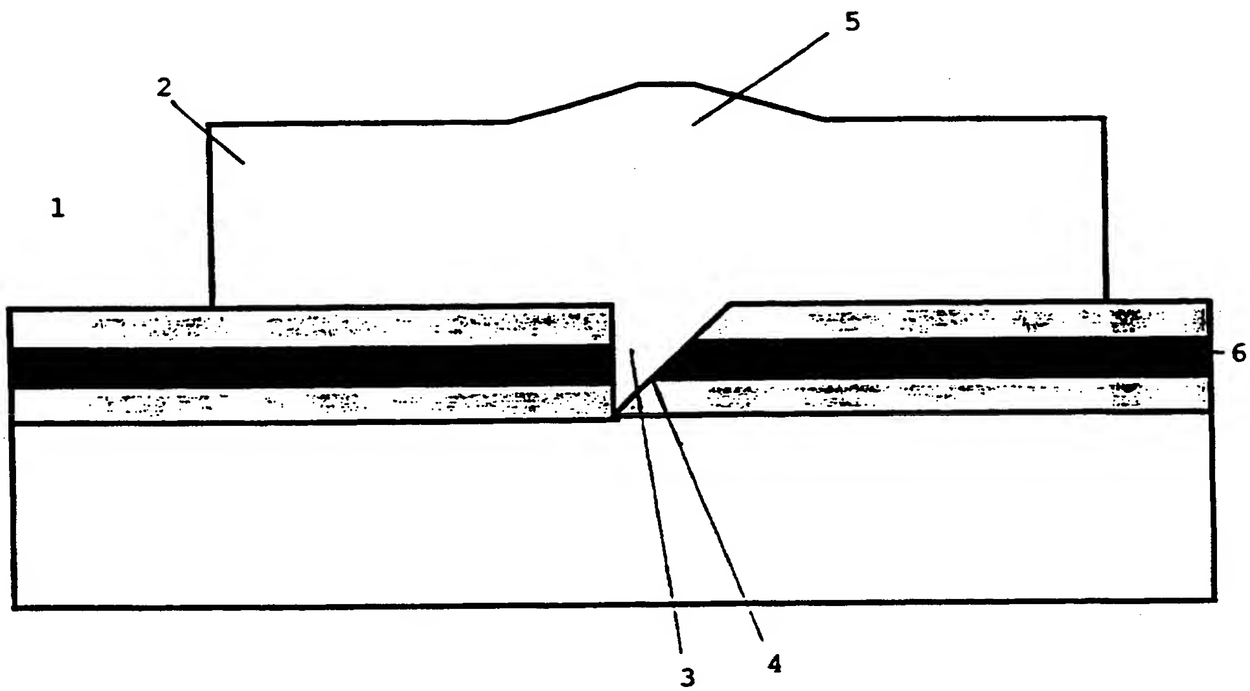


FIG.2

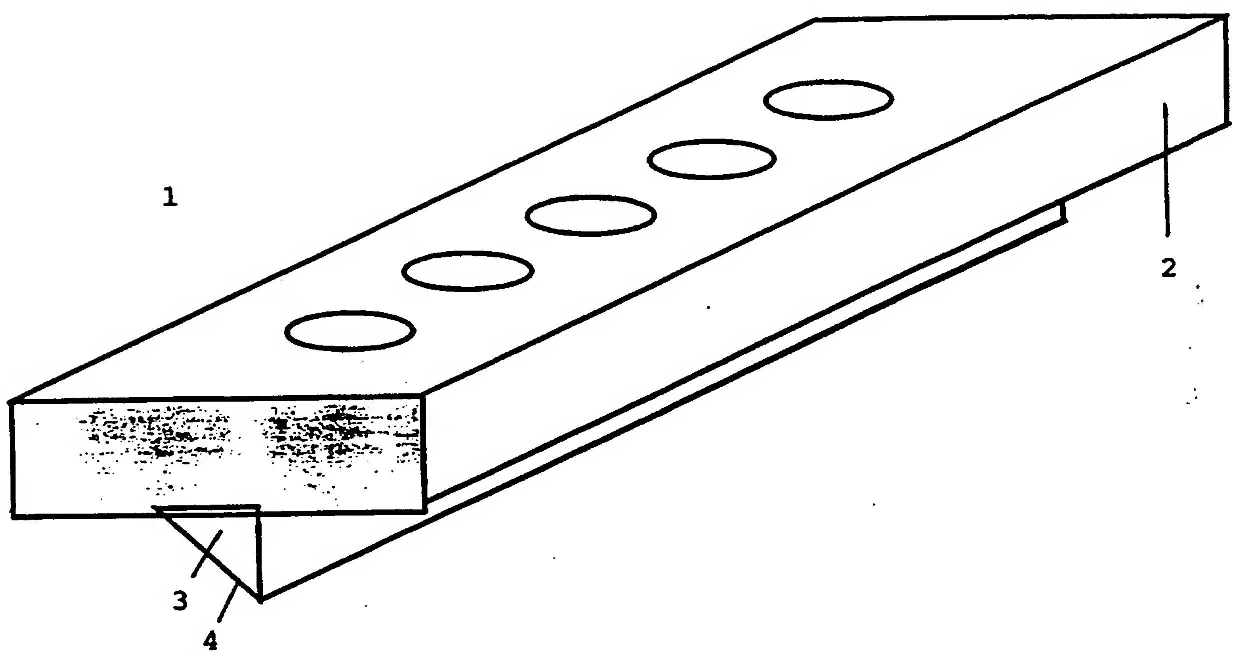
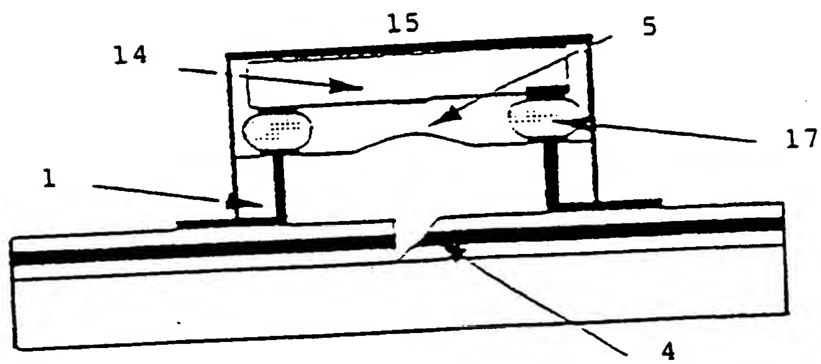


FIG.3

FIG. 4



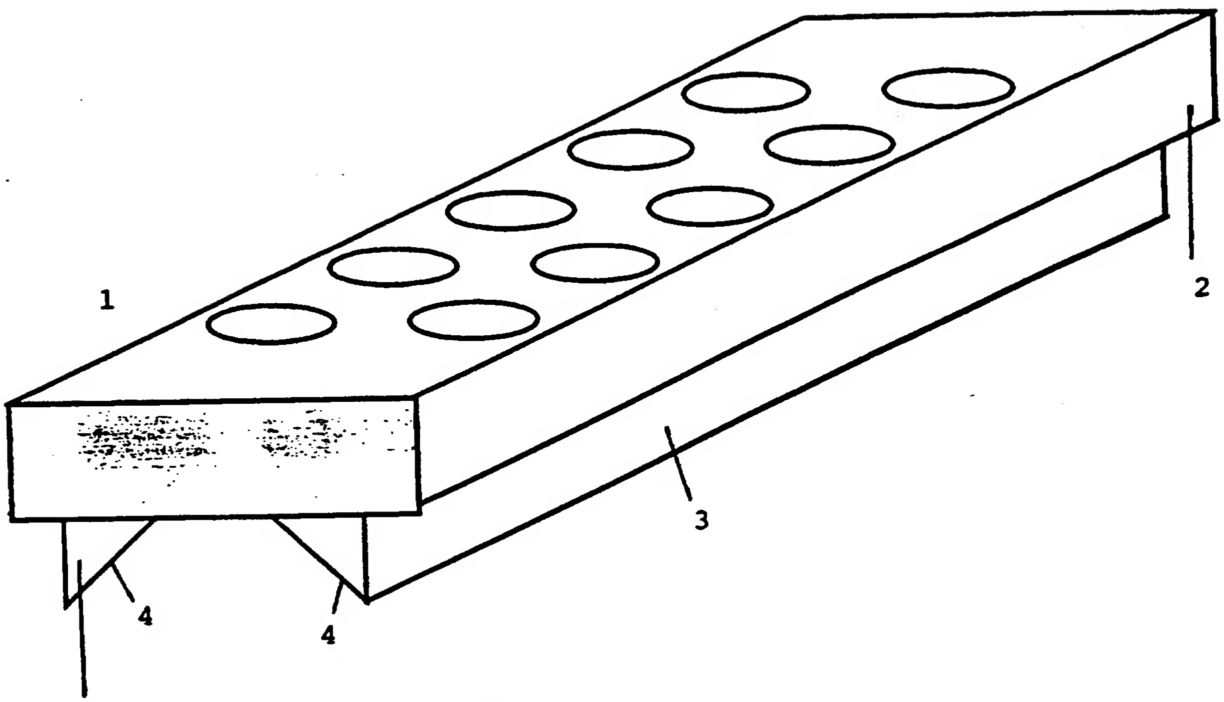


FIG.5

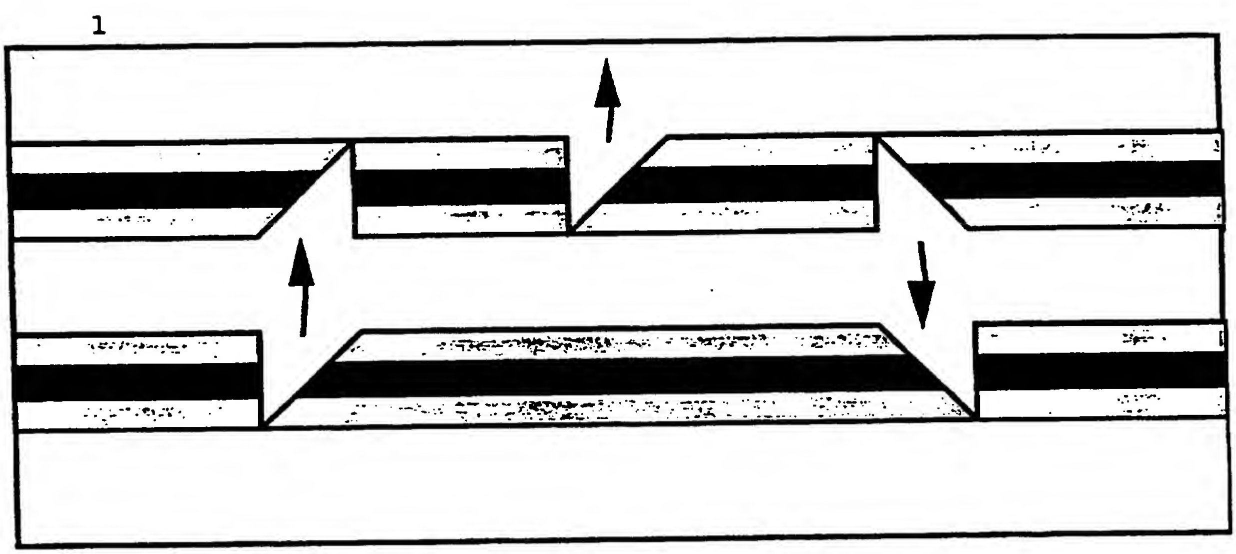


FIG.6

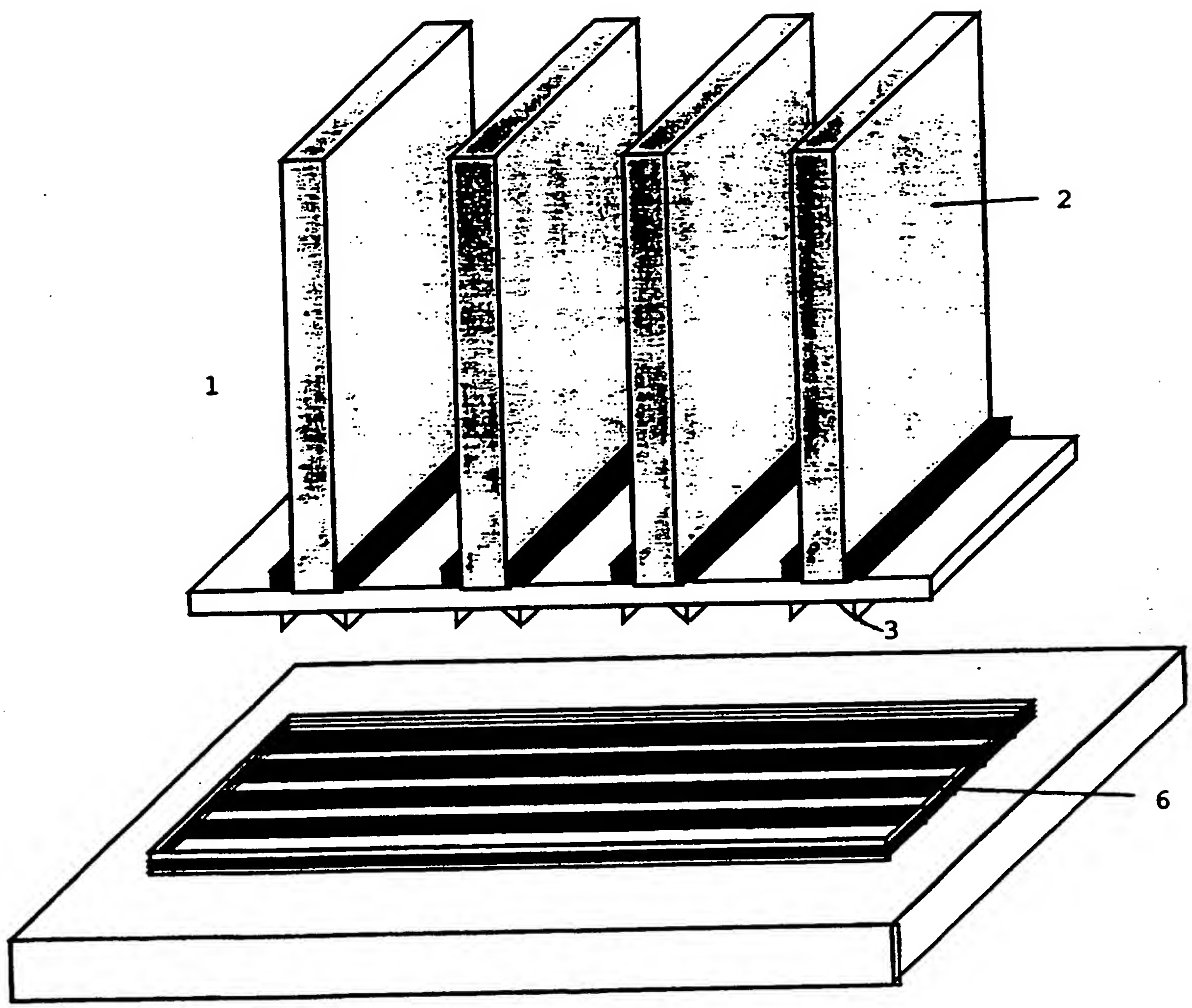


FIG. 7

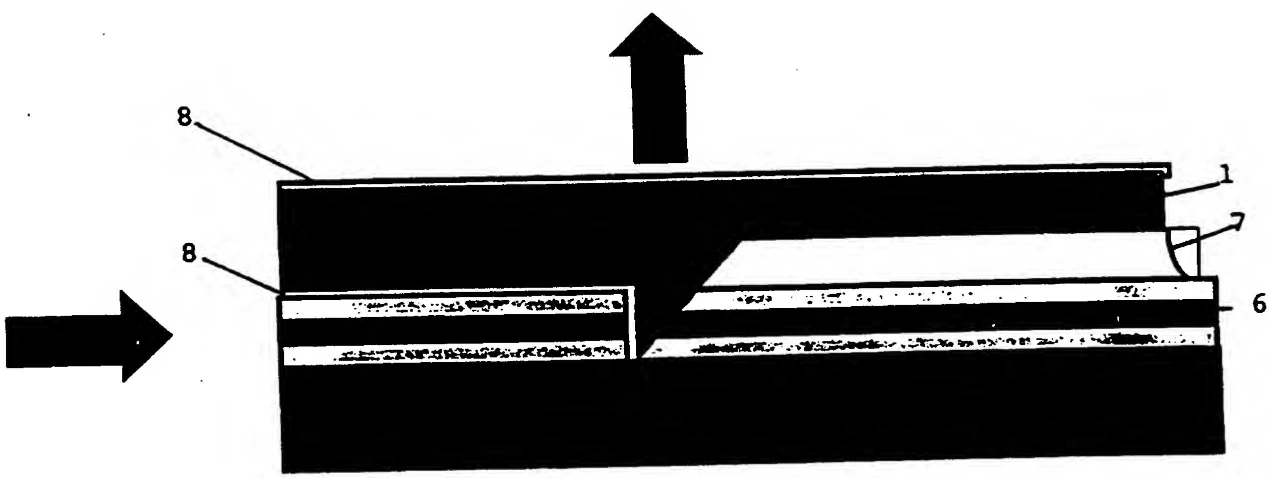


FIG.8

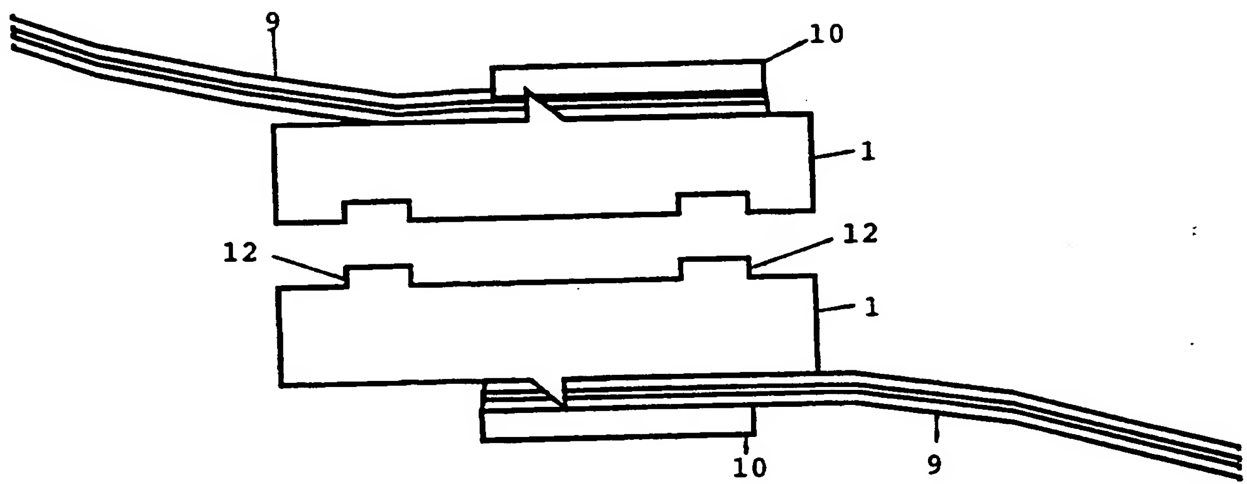


FIG.9

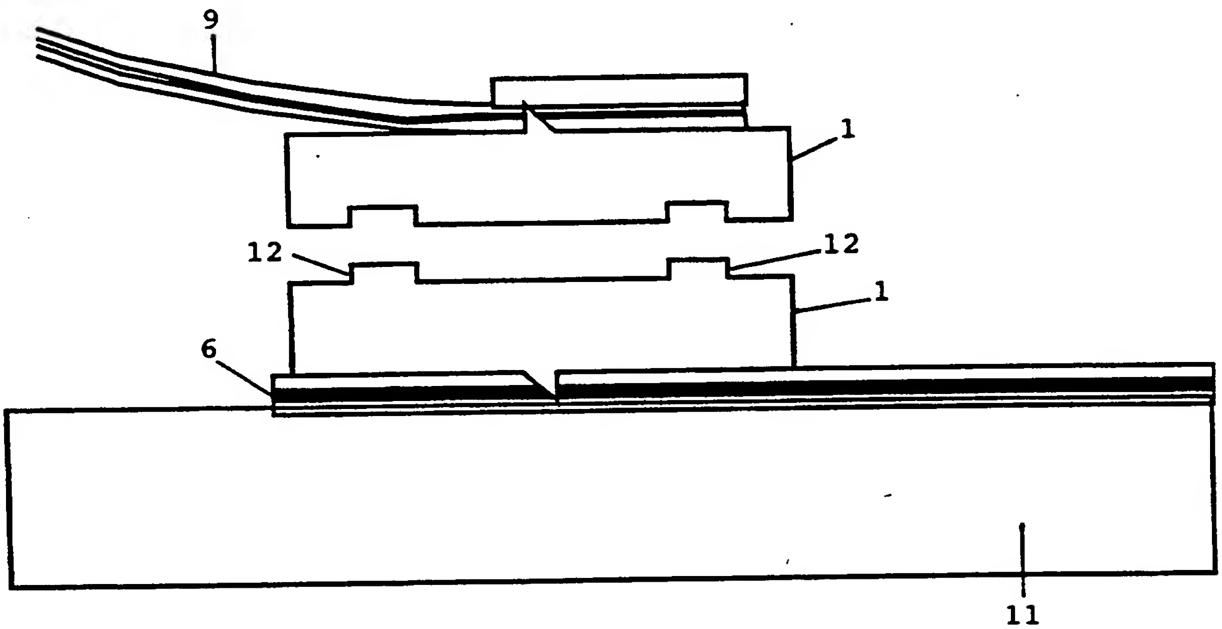


FIG.10

INTERNATIONAL SEARCH REPORT

Int. ...onal Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B6/28 G02B6/13

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB,A,2 168 165 (AB ELECTRONIC COMPONENTS) 11 June 1986 see page 1, line 18 - line 61; figures 2,3 ---	1,3,6,9
A	EP,A,0 594 089 (MINNESOTA MINING AND MANUFACTURING CO.) 27 April 1994 see page 14, line 13 - line 19; figures 1,6,7,11 ---	1
A	PATENT ABSTRACTS OF JAPAN vol. 8 no. 10 (P-248) ,18 January 1984 & JP,A,58 171019 (MATSUSHITA DENKO) 7 October 1983, cited in the application see abstract ---	1,3,6,8,9
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[X] Further documents are listed in the continuation of box C.

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Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 005 no. 154 (P-082) ,29 September 1981 & JP,A,56 085703 (FUJITSU LTD) 13 July 1981, see abstract ---	1,3,8,9
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.1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
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